J Raptor Res. 23(4):140–146

ENVIRONMENTAL CONTAMINANTS IN BLOOD OF WESTERN BALD EAGLES

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ABSTRACT.—Blood samples collected in 1979–81 from wintering Bald Eagles (*Haliaeetus leucocephalus*) in Oregon and northern California, residents in Oregon, migrants in Montana and residents in Washington were analyzed for lead (Pb), mercury (Hg) and organochlorines. Lead was detected infrequently (5%) and at low concentrations (<0.25 ppm) in nestlings from Oregon, more frequently (41%) and at occasionally elevated concentrations (>0.40 ppm) in wintering Bald Eagles in Oregon and northern California and migrants in Montana, and most frequently (56%) in nestlings from Washington but at low concentrations (<0.40 ppm). Mercury concentrations were low (<0.70 ppm) in samples from Washington nestlings and higher in samples from Oregon and northern California birds and in Montana migrants. Adults tended to have higher concentrations of Hg than hatch year birds or nestlings. Two Bald Eagles from Montana had clearly elevated Hg concentrations (7.0 and 9.5 ppm). DDE and polychlorinated biphenyl (PCB) concentrations were generally low (most means <0.20 ppm) with adults having higher concentrations than subadults or nestlings. A few resident adult Bald Eagles from Oregon had elevated concentrations of DDE.

Bald Eagle (*Haliaeetus leucocephalus*) populations in the United States and Canada have been adversely impacted by environmental contaminants. DDE has been strongly implicated in reduced reproductive success (Grier 1982; Wiemeyer et al. 1984a), and birds have died of dieldrin and endrin poisoning (Kaiser et al. 1980; Reichel et al. 1984). Bald Eagles also have died of lead (Pb) poisoning (Kaiser et al. 1980; Reichel et al. 1984), primarily caused by ingesting Pb shot from hunter-crippled and killed waterfowl (Pattee and Hennes 1983). Although some Bald Eagles have been exposed to mercury (Hg) contamination, most populations do not appear to have been affected (Belisle et al. 1972; Wiemeyer et al. 1984a).

Environmental contaminants in Bald Eagle populations have been monitored through analysis of tissues of birds found dead (Reichel et al. 1984), eggs (Wiemeyer et al. 1984a) and blood, including plasma (Henny et al. 1981; Pattee and Hennes 1983). We collected blood samples for contaminant analyses from Bald Eagles in Oregon, northern California, Montana and Washington. Our objectives were to determine contaminant concentrations in the birds, to compare concentrations among areas, age classes and residency status, and relate concentrations to sources of exposure and possible effects on populations.

METHODS

Sample Collection. Blood samples (6–12 cc) were collected in 1979–81 during the breeding season from resident (including 7–11-wk-old nestlings and adults) and subadult Bald Eagles from the Klamath Basin and Cascade Lakes areas of Oregon, and from wintering Bald Eagles from the Klamath Basin, Oregon and northern California (Frenzel 1985). Blood samples were taken with heparinized glass syringes (washed with detergent and rinsed with residue grade acetone) then frozen.

Blood samples (ca. 10 cc) were collected from migrant Bald Eagles in Glacier National Park (GNP), Montana (McClelland et al. 1982) during October–December 1980 and October–November 1981 using disposable syringes. Samples collected in 1980 were preserved with formalin (1 part/20 parts blood; Wiemeyer et al. 1984b); those collected in 1981 were preserved by freezing. Some birds were equipped with patagial markers and radio transmitters to monitor movements (Young 1983).

Blood samples (6 cc) were collected from 7–9-wk-old nestling Bald Eagles in San Juan Island County, Washington during June 1980 with heparinized disposable syringes. Samples were preserved with formalin. A sample of formaldehyde from the lot used in preserving blood samples was also submitted for chemical analysis.

Blood samples (5 cc) were collected from 5 captive Bald Eagles at the Patuxent Wildlife Research Center, Laurel, Maryland on 19 October 1983 for comparative purposes, using disposable syringes. Birds had been in captivity for 1–13 yrs. Samples were frozen. Two unused syringes from the same lot used in collecting blood samples were also submitted for chemical analysis.

Blood samples were placed in glass jars that had been cleaned with nitric acid and rinsed with deionized water, acetone and hexane, and capped with lids equipped with teflon liners.

Bald Eagles, except for nestlings, were aged on the basis of plumage characteristics. Eagles with white heads were classified as adults. In Oregon and California, all eagles lacking a white head were classified as subadults. In Montana, nonadult eagles were classified as hatch year birds or as subadults. Birds having the "dark immature" plum-

age (with dark brown eye and completely dark brown or black bill) as described by Clark (1983) were classified as hatch year; older nonadult birds (with varying degrees of lighter plumage, eye and bill coloration) were classified as subadults. Ages of nestlings were estimated by development of plumage (Stalmaster 1987), size and nesting chronology.

Chemical Analysis. Samples were homogenized and subsampled for various analyses. A 0.5 g aliquot was used for Pb analysis, 2.0 g for Hg and 5.0 g for organochlorines.

Organochlorines were analyzed by the methods of Cromartie et al. (1975) and Kaiser et al. (1980), except that fractions I and II were combined. Glassware was rinsed with 15% ethyl ether in hexane prior to use. Contaminants in each fraction were identified and quantitated by electron capture gas chromatography using a 1.5/1.95% SP-2250/SP-2401 packed column. The lower limit of reportable residues was 0.01 ppm for pesticides and 0.05 ppm for polychlorinated biphenyls (PCBs) in Oregon and northern California samples, and 0.05 ppm for pesticides and 0.10 ppm for PCBs in Montana samples. A gas chromatograph-mass spectrometer was used to confirm the identity of contaminants in about 10% of samples containing detectable concentrations.

Samples were analyzed for Hg by cold vapor atomic absorption spectrophotometry using previously described methods (Monk 1961; Hatch and Ott 1968). The lower limit of reportable residues was 0.02 ppm. Lead was analyzed by graphite furnace atomic absorption spectrophotometry using a wet ash procedure (Hinderberger et al. 1981). The lower limit of reportable residues was 0.05 ppm.

Frozen duck blood samples stored for 2 and 8 mo lost 35% of their DDE concentrations compared to those analyzed fresh, whereas no DDE was lost from samples preserved with formalin and stored for the same periods (Wiemeyer et al. 1984b). Data on the stability of PCBs under these preservation methods are not available. Freezing and formalin preservation of blood were equally suitable when dealing with Pb and Hg residues (Wiemeyer et al. 1984b). Only samples from Montana in 1980 and from Washington nestlings in this study were preserved with formalin.

Samples from Oregon and California were stored frozen for 8–24 mo before chemical analysis. Samples from Montana that were collected in 1980 were analyzed for organochlorines in August 1981 and for Pb and Hg in February 1983. Montana samples collected in 1981 were analyzed for organochlorines and metals in July and November 1982, respectively. Samples from Washington were analyzed in September 1982. Samples from captive birds were analyzed within 3 wk of collection.

Lead or Hg was not detected in a sample of formalin from the lot used to preserve samples from Washington. Mercury was not detected in solutions used to rinse syringes from the same lot as those used in collecting blood samples from captive Bald Eagles.

Statistical Analysis. Geometric means are reported throughout when ≥50% of samples contained a detectable concentration of a given contaminant. Samples containing nondetectable residues were assigned values equal to one-half the detection limit in computing means. T-tests were used to determine if significant differences occurred between means of log transformed values.

RESULTS

Lead was detected infrequently (5%) and at low concentrations in nestling Bald Eagles from Oregon (Table 1), but more frequently in Washington nestlings (χ^2; $P < 0.001$). Forty-one percent of samples from wintering Bald Eagles in Klamath Basin and also in migrants from Montana had detectable Pb concentrations. Only 3 samples from all areas contained >0.4 ppm Pb, 2 migrants from Montana and 1 wintering subadult from Klamath Basin.

All but 1 sample contained detectable Hg concentrations (Table 1). Concentrations ranged widely, with the lowest mean concentration found in nestlings from Washington and the highest in subadults and adults from Oregon and northern California. Oregon nestlings had significantly higher ($P < 0.0001$) concentrations than Washington nestlings. Subadults and adults tended to have higher Hg concentrations than nestlings or hatch year birds. Concentrations in Oregon resident adults were significantly higher ($P = 0.019$) than in Oregon nestlings. Blood samples from 5 captive Bald Eagles contained a mean of 0.23 ppm Hg (range 0.17–0.31 ppm).

The primary organochlorines detected were DDE and PCBs (Table 2); however, DDD, *trans*-nonachlor and *cis*-nonachlor were detected in a few samples from Oregon (Frenzel 1985). DDE was detected in 61% of samples from Oregon nestlings and 100% of samples from subadults and resident adults. DDE was detected in 95% of samples from subadults and adults wintering in Oregon and northern California. Polychlorinated biphenyls were detected much less frequently than DDE in samples from Oregon and northern California; only 15% of samples from nestlings and 59% of samples from subadults and adults contained detectable concentrations. Samples from resident adults in Oregon contained significantly ($P < 0.0001$) higher DDE and PCB concentrations than did nestlings from the same area. Resident adults from Oregon had significantly ($P < 0.0001$) higher DDE and PCB concentrations than those of wintering adults from the Klamath Basin. Few samples from migrant Bald Eagles from Montana contained detectable DDE and PCB concentrations, although the lower limits of reportable residues were higher than for Oregon and northern California samples. DDE was detected most frequently in adults.

Table 1. Frequency of occurrence and concentrations (ppm wet weight) of lead (Pb) and mercury (Hg) in blood samples from western Bald Eagles.

	Pb				Hg		
	Number						
State, Status and Age	Sampled	With Detectable[a]	Geometric Mean	Range	Number Sampled[b]	Geometric Mean	Range
Oregon							
Resident							
Nestling	58	3	—	nd[c]–0.22	82[d]	1.2	nd–4.2
Subadult[e]	2	0	—	—	2	3.0	2.8–3.2
Adult	5	1	—	nd–0.25	7	2.3	1.1–4.8
Oregon and northern California							
Wintering[f]							
Subadult	4	3	0.129	nd–0.62	5	2.2	1.6–2.7
Adult	13	4	—	nd–0.25	15	2.3	1.1–5.4
Montana							
Migrant							
Hatch year	12	4	—	nd–0.23	12	1.5	0.94–3.2
Subadult	14	7	0.072	nd–1.9	14	1.8	0.89–9.5
Adult	3	1	—	nd–1.9	3	2.0	0.85–4.5
Washington							
Resident							
Nestling	9	5	0.066	nd–0.36	9	0.23	0.075–0.65

[a] Lower limit of reportable residues 0.05 ppm.
[b] All samples contained Hg except as noted in footnote d.
[c] nd = none detected.
[d] One sample contained no detectable Hg.
[e] These birds were probably nomadic and not true residents even though they were sampled during the breeding season.
[f] Data from Frenzel and Anthony (1989).

Discussion

Lead. Only 3 eagles in our study had recent significant exposure (>0.40 ppm Pb in blood) to Pb. Although a number of additional eagles had detectable Pb concentrations in blood (evidence of Pb exposure), their exposure appeared minimal. Bald Eagles that were experimentally dosed with 10 pellets of No. 4 Pb shot had a mean of 0.8 ppm Pb in blood 1 d after dosage and 2.8 ppm 3 d after dosage, whereas unexposed Bald Eagles had no detectable Pb concentrations (<0.1 ppm) in their blood (Hoffman et al. 1981).

Bald Eagles wintering in Klamath Basin fed mostly on waterfowl (Frenzel and Anthony 1989), whereas fish were predominant in the diet of resident eagles during spring and summer (Frenzel 1985). Detectable Pb concentrations were found more frequently in adult and subadult Bald Eagles wintering in Klamath Basin (41%) than in subadults and resident adults from Oregon (14%); however, the difference was not significant (χ^2; $P = 0.20$). Seasonal shifts in food habits and the possible entry of birds into the wintering population that could have been previously exposed to Pb may explain these differences; however, larger samples would be required to examine this issue. Most Bald Eagle food items from Oregon had low concentrations of Pb in carcass, except for grebes, gulls and Belding's Ground Squirrels (*Spermophilus beldingi*) (Frenzel 1985). The most likely source of Pb exposure to Bald Eagles is ingestion of Pb shot from hunter-killed or crippled waterfowl (Pattee and Hennes 1983).

Migrant Bald Eagles in GNP fed on fish (McClelland et al. 1982). Lead was detected in none

Table 2. Frequency of occurrence and concentrations (ppm wet weight) of organochlorines in blood samples from western Bald Eagles.

STATE, STATUS, AGE AND COLLECTION YEAR	N	DDE			PCB		
		NO. WITH DETECTABLE[a]	GEOMETRIC MEAN	RANGE	NO. WITH DETECTABLE[b]	GEOMETRIC MEAN	RANGE
Oregon[c]							
Resident							
Nestling	75	46	0.015	nd[d]–0.15	11	—	nd–0.29
Subadult[e]	3	3	0.12	0.06–0.20	1	—	nd–0.08
Adult	8	8	0.50	0.08–1.4	8	0.25	0.05–0.71
Oregon and northern California[c]							
Wintering[f]							
Subadult	5	5	0.030	0.01–0.14	2	—	nd–0.08
Adult	16	15	0.042	nd–0.13	8	0.018	nd–0.12
Montana							
Migrant							
Hatch year							
1980[g]	5	0	—	—	0	—	—
1981[c]	6	0	—	—	0	—	—
Subadult							
1980[g]	5	2	—	nd–0.06	0	—	—
1981[c]	5	0	—	—	0	—	—
Adult							
1980[g]	7	7	0.19	0.07–0.71	4	0.28	nd–0.71
1981[c]	3	3	0.086	0.05–0.13	0	—	—

[a] Lower limit of reportable residues 0.01 ppm for Oregon and northern California samples and 0.05 ppm for Montana samples.
[b] Lower limit of reportable residues 0.05 ppm for Oregon and northern California samples and 0.10 ppm for Montana samples.
[c] Samples preserved by freezing.
[d] nd = none detected.
[e] These birds were probably nomadic and not true residents even though they were sampled during the breeding season.
[f] Data from Frenzel and Anthony (1989).
[g] Samples preserved with formalin.

of 8 samples collected on or before 25 October, whereas 12 of 21 (57%) samples collected after that date had detectable concentrations (χ^2; $P = 0.005$). Samples from subadults and adults ($N = 2$ and 0, respectively) were poorly represented in the earlier time period. For hatch year birds only, none of 6 samples collected on or before 25 October had detectable Pb concentrations, whereas 4 of 6 collected later had detectable concentrations (χ^2; $P < 0.025$). Exposure to Pb shot would be expected to increase after the start of the waterfowl hunting season and may have occurred before arrival in GNP.

One adult female Bald Eagle found dead in Klamath Basin in 1982 died of Pb poisoning; liver contained 27 ppm Pb (Frenzel and Anthony 1989). Lead concentrations in livers of 11 other adult and subadult Bald Eagles from Oregon and northern California that died in 1979–82 were <6 ppm; 7 were <2 ppm (Frenzel 1985). Twenty-two Bald Eagles dying in Oregon, Montana, and Washington were necropsied during 1978–81; none died of Pb poisoning (Reichel et al. 1984). Bald Eagles dosed with Pb shot all had >10 ppm Pb in liver at death (Pattee et al. 1981).

Although the exposure of Bald Eagles to Pb in our study areas generally appeared low, even some nestlings were exposed. A few migrant and wintering Bald Eagles were at risk from Pb poisoning. Additional information relating known Pb concentrations in blood of Bald Eagles to effects on health and risk of poisoning would be helpful in interpreting data from field studies. The eventual ban on use of

Pb shot in waterfowl hunting in the 1991–92 hunting season (U.S. Fish and Wildlife Service 1986) should greatly reduce the risk of Bald Eagles dying of Pb poisoning. Studies on exposure of wild Bald Eagles to Pb following the ban should be conducted to determine impact on populations.

Mercury. Bald Eagles appear to routinely have higher concentrations of Hg in their blood than other species of birds. For example, nearly all untreated Mallards (*Anas platyrhynchos*) had <0.07 ppm in blood (Heinz 1980), whereas wild Rock Doves (*Columba livia*) from Mississippi had 0.005–0.012 ppm Hg in blood (Knight and Harvey 1974). Nestling Bald Eagles from Washington and captive Bald Eagles both had means of 0.23 ppm Hg in blood. Young Common Terns (*Sterna hirundo*) from Long Island, New York that may have been exposed to minor Hg contamination and were classified as normal with regard to feather development had 0.37 μg/ml Hg in blood (Gochfeld 1980). Mallards fed 0.5 ppm (dry weight) methylmercury for 7 mo had blood levels of 0.5 to 0.6 ppm Hg (Heinz 1980).

Wild Bald Eagles, except for Washington nestlings, in our study had far higher Hg concentrations in blood. Fifteen eagles had >3 ppm Hg in blood (11 from Oregon or northern California and 4 from Montana). Two Montana eagles, both subadults, had >6 ppm in blood (7.0 and 9.5 ppm). Higher concentrations in blood samples of adults than in those from nestlings and hatch year birds correspond with the known accumulative nature of Hg.

Although Bald Eagle blood samples from Oregon and northern California had higher concentrations than other species or captive Bald Eagles, there is no evidence that Hg was having an adverse impact on the population. Reproductive success appeared normal (Frenzel 1985). Eight clutches of Oregon Bald Eagle eggs from the Klamath Basin and Cascade Lakes regions collected during 1979–81 contained <0.26 ppm Hg (clutch means) (Frenzel 1985). Eight of 9 Bald Eagles found dead in the same area during 1979–82 had <3 ppm Hg in liver, with 1 bird having 8 ppm (Frenzel 1985). These concentrations are far below those associated with effects on reproduction (0.5 to 1.5 ppm in eggs; Wiemeyer et al. 1984a) or survival (>20 ppm in liver; Finley et al. 1979). Mercury residues in prey of Oregon Bald Eagles also tended to be low (Frenzel 1985).

Some Bald Eagles migrating through GNP may have been exposed to Hg contamination in Canada. Transmitter-equipped Bald Eagles migrating through GNP were tracked to summering areas in Northwest Territories (NWT) and northeastern Alberta, Canada (Young 1983). Elevated Hg concentrations in fish have been reported for several Canadian areas within the migratory corridor of some Bald Eagles passing through GNP, to include: Giauque and Thompson Lakes, 100–125 km north of Great Slave Lake, NWT (Moore and Sutherland 1980); the North Saskatchewan River, near Edmonton, Alberta (Ramamoorthy et al. 1985); and some lakes in northern Saskatchewan, especially Cumberland Lake on the Saskatchewan River (Murray 1978). A Bald Eagle found dead in Montana south of GNP in March 1985 had 35 ppm (wet weight) Hg in liver, a concentration suggesting Hg poisoning.

The western states and British Columbia lie in a mercuriferous belt where underlying rock contains elevated Hg levels (Jonasson and Boyle 1971). This naturally occurring source of Hg in the region may contribute to Hg in food chains and subsequently in Bald Eagles. However, this source should contribute little to Hg found in hatch year Bald Eagles migrating through GNP, their origin in Canada being outside the mercuriferous belt. Mercury residues in blood of hatch year Bald Eagles sampled in GNP were not correlated ($P > 0.05$) with date of collection.

Lack of information relating known exposures of Hg to concentrations in blood and effects on health of Bald Eagles prevents adequate interpretation of our data. Therefore, risk cannot be assessed. The presence of highly elevated concentrations in a few birds is cause for concern. Data on sources of exposure could lead to control thus reducing risk to Bald Eagles.

Organochlorines. Direct comparisons of DDE concentrations between samples that were preserved by freezing and those that were preserved with formalin should be conducted with caution (see Methods).

Organochlorine concentrations in plasma or serum of birds have been significantly correlated with concentrations in tissues, making possible the monitoring of contamination in wild populations without sacrifice of birds (Capen and Leiker 1979; Friend et al. 1979; Henny and Meeker 1981). The nature of the relationship between organochlorine concentrations in whole blood and that in carcass or other tissues is unknown for Bald Eagles. Henny and Meeker (1981) predicted DDE burdens in eggs based

on residues in plasma of laying females for American Kestrels (*Falco sparverius*) and accipiters. Application of predictive equations to our data is questionable because of differences in residue concentrations between plasma and whole blood and possible species differences. Plasma should contain about twice the concentration in whole blood. Relative DDE concentrations in blood from resident adult Bald Eagles from Oregon were similar to the relative DDE concentrations in eggs (Frenzel 1985). Concentrations of DDE in eggs from the southern Oregon population were high enough to be associated with eggshell thinning and reproductive failure for a few breeding pairs (Wiemeyer et al. 1984a; Frenzel 1985). A few resident adult Bald Eagles from Oregon had clearly elevated DDE concentrations in blood. Henny et al. (1981) found low Σ DDT (almost all DDE) concentrations ($\bar{x}$ = 0.06–0.14 ppm) in plasma of Bald Eagles wintering in Colorado and Missouri in 1977–78. Organochlorine concentrations in the environment have declined following bans and restrictions on usage which should result in continuation of reduced risks to Bald Eagles.

ACKNOWLEDGMENTS

We thank M. L. Gay for analytical methods and A. J. Krynitsky, J. F. Moore and B. M. Mulhern for analysis of samples. P. T. McClelland, L. S. Young, J. C. Crenshaw, H. A. Allen and R. H. Fevold assisted with blood sample collection in GNP. D. K. Garcelon and T. G. Grubb assisted with field work in Washington. J. D. Anderson, D. K. Edwards, F. B. Isaacs and G. S. Miller assisted with field work in Oregon and northern California. O. H. Pattee, C. P. Rice and C. J. Henny provided helpful comments on earlier drafts of the manuscript.

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Received 20 December 1988; accepted 15 August 1989